NASA Innovative Advanced Concepts

Soft-Robotic Rover with Electrodynamic Power Scavenging

Completed Technology Project (2014 - 2015)

Project Introduction

We propose a rover architecture for Europa and other planetary environments where soft robotics enables scientific investigation or human-precursor missions that cannot be accomplished with solar or nuclear power. This rover resembles a squid, with tentacle- like structures that serve both as electrodynamic tethers to harvest power from locally changing magnetic fields and as a means of bio-inspired propulsion. The electrical energy scavenged from the environment powers all rover subsystems, including one that electrolyzes H20. Electrolysis produces a mixture of H2 and O2 gas, which is stored internally in the body and limbs of this rover. Igniting this gas expands these internal chambers, causing shape change to propel the rover through fluid or perhaps along the surface of a planetary body. The Phase I effort constitutes advancement of this revolutionary rover concept from TRL 1 to TRL 2. The work will be conducted at Cornell University, led by PI Mason Peck and Co-I Robert Shepherd. If the concept eventually succeeds, it will enable amphibious exploration of gas-giant moons, notably Europa. It likely is relevant to other moons of Jupiter and Saturn with liquid lakes or oceans. Juno's success notwithstanding, solar power near Jupiter is very limited. Furthermore, the recent cancellation of SMD's ASRG technology motivates alternatives to nuclear power. The bio-inspired technologies we propose to consider bypass the need to power rovers with limited-lifetime batteries, large solar arrays, or nuclear power. In this one respect, it is a breakthrough concept. Beyond addressing issues of power, this rover concept also bypasses the difficulties of typical mechanisms in fluid through uniquely suited soft robotics. The expanding-gas locomotion concept is both exotic and eminently realizable, grounded in experimental work by our team.

Anticipated Benefits

If the concept eventually succeeds, it will enable amphibious exploration of gas-giant moons, notably Europa. It likely is relevant to other moons of Jupiter and Saturn with liquid lakes or oceans. Juno's success notwithstanding, solar power near Jupiter is very limited. Furthermore, the recent cancellation of SMD's ASRG technology motivates finding alternatives to nuclear power. The bio-inspired technologies we propose to consider bypass the need to power rovers with limited-lifetime batteries, large solar arrays, or nuclear power. This breakthrough should be considered in contrast to more familiar Europa rover designs, many of which involve nuclear power or primary batteries that severely limit lifetime and power-to-weight (~ 100W/kg power density for our concept vs. 1-5 W/kg at best for nuclear systems). Beyond addressing issues of power, this rover concept also bypasses the difficulties of typical mechanisms in fluid through uniquely suited soft robotics. The expanding-gas locomotion concept is both novel and eminently realizable, grounded in experimental work by our team. The multiple-use philosophy here exploits synergies among structure, power, and the environment in a way that differs from typical rovers, where stovepiped subsystem designs do not take

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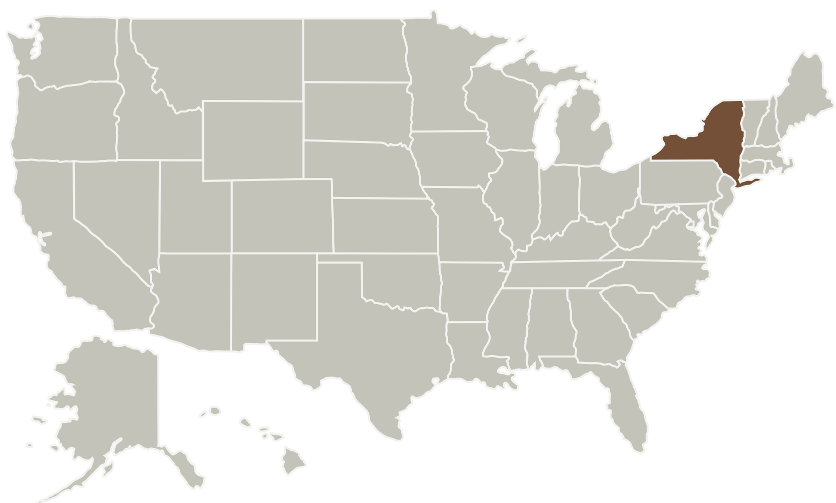
advantage of prospective mass savings. Additionally, many of the proposed systems are useful to marine operations on Earth, where batteries or energy harvesting devices could be used to power the electrolyzer subsystem. Extending the applicability of this exotic concept to terrestrial applications is in the best traditions of NASA's spinoffs and offers additional economic benefit. This study also is expected to offer NASA a return on its investment in the nearer term. This work will assess the possibility that any life on Europa may be powered by electromagnetic energy, with singular implications for astrobiology. That scientific benefit may influence future directions in Europa exploration. More broadly, this study will serve as a pathfinder that introduces soft robotics into future rover trades.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Cornell University	Lead Organization	Academia	Ithaca, New York

Primary U.S. Work Locations
New York

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Cornell University

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

Eric A Eberly

Principal Investigator:

Mason A Peck

Co-Investigator:

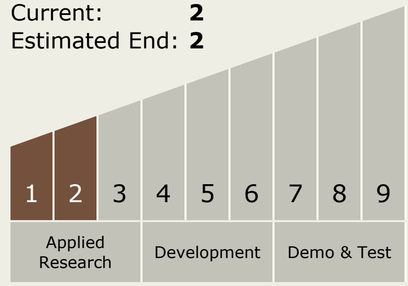
Robert G Shepherd

Project Transitions

December 2014: Project Start

Technology Maturity (TRL)

Start: **1**
Current: **2**
Estimated End: **2**



Technology Areas

Primary:

- TX03 Aerospace Power and Energy Storage
  └ TX03.1 Power Generation and Energy Conversion
    └ TX03.1.6 Other Advanced Concepts for Generating/Converting Power

Target Destination

Others Inside the Solar System

July 2015: Closed out

Closeout Summary: The purpose of studying the capabilities of Electrodynamic Tethers (EDT) and Soft Robotics is to asce rtain the feasibility of using cross-cutting EDT and soft robotics technologies to achieve future NASA mission objectives with mass and power budgets orders of magnitude lower than conventional spacecraft. In this context, the Phase I study focuse s on three technological elements: the design of a soft-robotic rover that can operate in extraterrestrial oceans, demonstrat ing feasibility of electrodynamic tethers for power scavenging in the Europa environment, and utilizing electrolysis to power biomimetic propulsion. The Phase I results show that a soft robotic, underwater rover has many advantages over a tradition al view of autonomous underwater vehicles. Many of these advantages stem from its ability to collapse or expand the body, which carries two key benefits: (i) cost savings in transport and (ii) buoyancy control. Furthermore, this rover's material off ers properties that enable it to survive most oceanic conditions, withstand a likely radiation environment, and retard ice for mation. The use of these soft robots under water is very attractive because buoyancy enables very large robots without the need for skeletal structures that limit their shape-changing ability. The prime limitation of soft robots for underwater explor ation is their nascent state of development, an issue that this study has begun to address and that we hope to continue in P hase II. The theoretical calculations and experimental investigation on electrodynamic tethers discussed in this report show that their use in saltwater environments is feasible. However, magnetohydrodynamic effects require attention, which will be a priority in Phase II. A possible approach involves magnetic shielding of a portion of the EDT array to generate significant c urrent from imposed alternating magnetic fields. The Phase I experiments show that this approach may enable enough pow er to be generated for a soft robotic rover of the scale contemplated here. This power is in the range of 1mW to 1W and det ermines the time required to collect and transmit science data. The interface between the EDT and rover resembles a fuel c ell. This tehnology generates the gases required to power the actuators and recombines these gases, if needed, to extract e lectricity for several subsystems. For example, there exist science instruments that complement the low mass and low pow er of our rover and still return substantial new science data. Examples include miniature mass spectrometers, voltammeter s, magnetometers, pressure sensors, temperature sensors, and other MEMS and soft sensors. Such a sensor suite can be u sed to determine chemical-composition data of nutrient particulates in the ocean, magnetic-field specifics, and pressure and temperature gradients. Designing a soft robotic rover for a mission to the Europan ocean requires a holistic view of the enti re mission--for example, accommodating issues of radiation exposure during transit, conditions in the ocean, and conditions during travel through ice. The Phase I study did not concentrate on EDL or passage through the ice, as explained in the Pha se I proposal, because JPL and others are already looking into those aspects of a mission. We incorporated these concepts i nto a general system architecture. The Europa environment is poorly understood due to the limited scientific data from whic h to draw conclusions. A mission centered on the proposed soft-rover technology holds promise for answering these conject ures with science data bolstering some definitive answers about the unique Europa environment. Despite these uncertaintie s, a soft rover has high potential of being capable of surviving in Europa's subsurface ocean environment. Phase I explored the concept of an eel- or squid-inspired rover. A key conclusion is that a buoyancy-controlled underwater glider may be the best use of a soft actuator's capabilities. The Phase I report summarizes mathematical models of buoyancy and underwater gliding for such a system. Additionally, the Phase I work shows that a rover can use hydrogen fuel for combustion powered hydrojetting. The combination of a buoyancy controlled glider and combustion powered hydrojetting can complement slow, long-duration, underwater exploration with the ability for rapid movements when necessary. As both buoyancy control and hydrojetting use fuel generated from sea water, the in-situ use of resources substantially reduces the launched system mas s necessary [1]. These results point to the real utility of both an EDT energy harvesting system and an underwater soft rob otic rover. The integration of the two systems via a fuel cell for in-situ resource use motivates further study in a proposed P hase II project.

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html